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NOAA Science On a Sphere™ Users Manual
Version 1.0 - April, 2004

1. Introduction

Science On a Sphere™ is the result of a National Oceanic and Atmospheric Administration (NOAA) program to develop a revolutionary system for educating the public on the holistic nature of Earth's ever-changing oceans, atmosphere, biology, and land. Science On a Sphere™ is typically used to project images of the Earth, Sun, Moon, or other planets. These bodies can be shown rotating or stationary, at any axis placement, with or without data or images displayed or animating over their surfaces.

At its most basic, NOAA Science On a Sphere™ is a visualization device that uses a number of video projectors, typically four, driven by a computer system to project images onto the outside of a large, opaque sphere. People move freely around this suspended sphere to view the image.

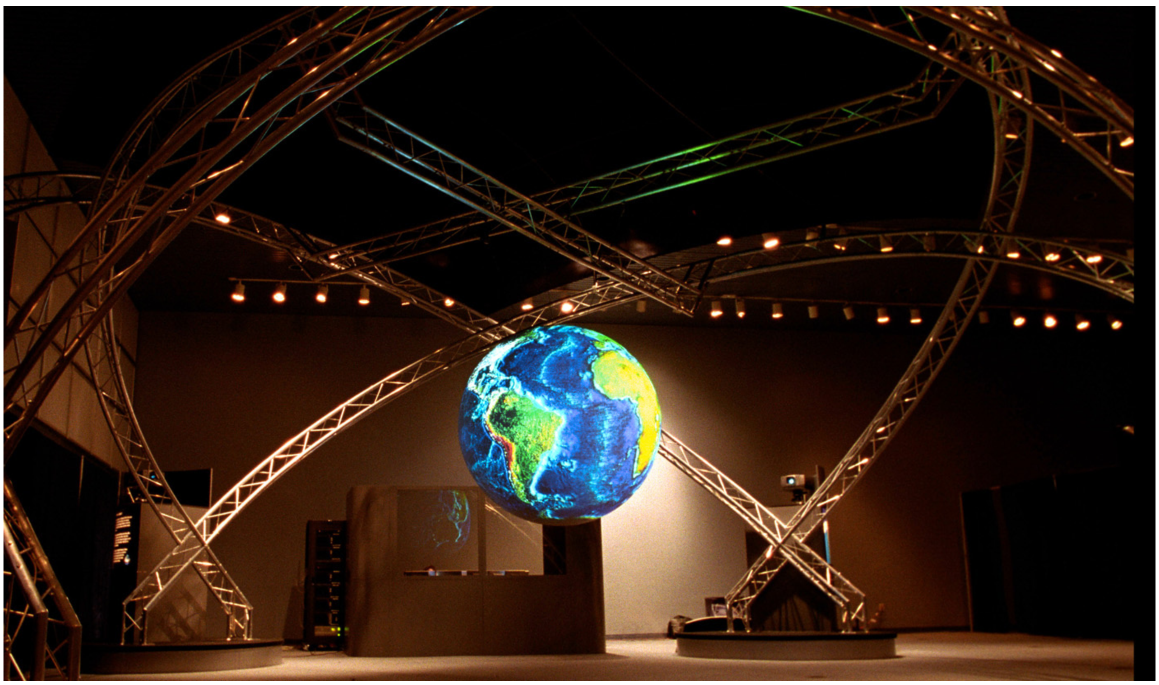


Figure 1: Science On a Sphere with a portable structure.

Nearly any global data can be displayed on Science On a Sphere, including weather, climate, geology, images of solar system bodies, or any type of geographical information that covers a large portion of a planet's surface. Some of the most popular images at NOAA include:

- A day-to-night rotation of the Earth, using high-resolution topography for the daylight side, and DMSP (Defense Meteorological Satellite Program) night light data on the dark side of the planet;
- Global infrared weather images compiled from a series of geostationary meteorological satellites;
- Weather prediction model output;
- Climate change simulations;
- 600 million years of plate tectonics;

- The Sun as seen by the GOES X-Ray Imager;
- The surfaces of the Moon and Mars.

Science On a Sphere provides an ideal way to educate the public on many important issues, both environmental and economic, that face the United States and the entire world. Since the sphere is essentially a movie screen, and since the sosrender software can render any equidistant cylindrical projection dataset with a 2:1 aspect ratio onto the sphere, the subject matter of the display material is essentially unlimited.

This manual covers the system architecture, initial system setup alignment, dataset creation, and routine system support. The appendices cover some of the datasets available from NOAA.

NOAA Science On a Sphere is a trademark of the National Oceanic and Atmospheric Administration (NOAA). It can only be used with the permission of NOAA or its properly designated agent.

A patent is pending for NOAA Science On a Sphere™.

2. System Architecture

Science On a Sphere™ uses what is called "streaming" architecture, so called because datasets are read directly from the internal hard drives and displayed in a continuous stream. The operator or show floor control system has full animation control, including starting, stopping, and the direction of the animation. This architecture is well suited for longer, video-style datasets. It also allows almost immediate access and animation of any of the available datasets with a minimal initial load time.

Figure 2 illustrates the basic system architecture. The system typically uses a single set of four PC-class display computers ("Alpha" 1 through 4) and a PC-class file server and control/synchronization computer or computers. All of the computers run the Linux® operating system. An additional set of one through four display computers can be run simultaneously as a "hot" backup (Spare-1 through -4). A number of different options are available for switching between the primary and backup display computers depending on the installation, and its need for uninterrupted data display.

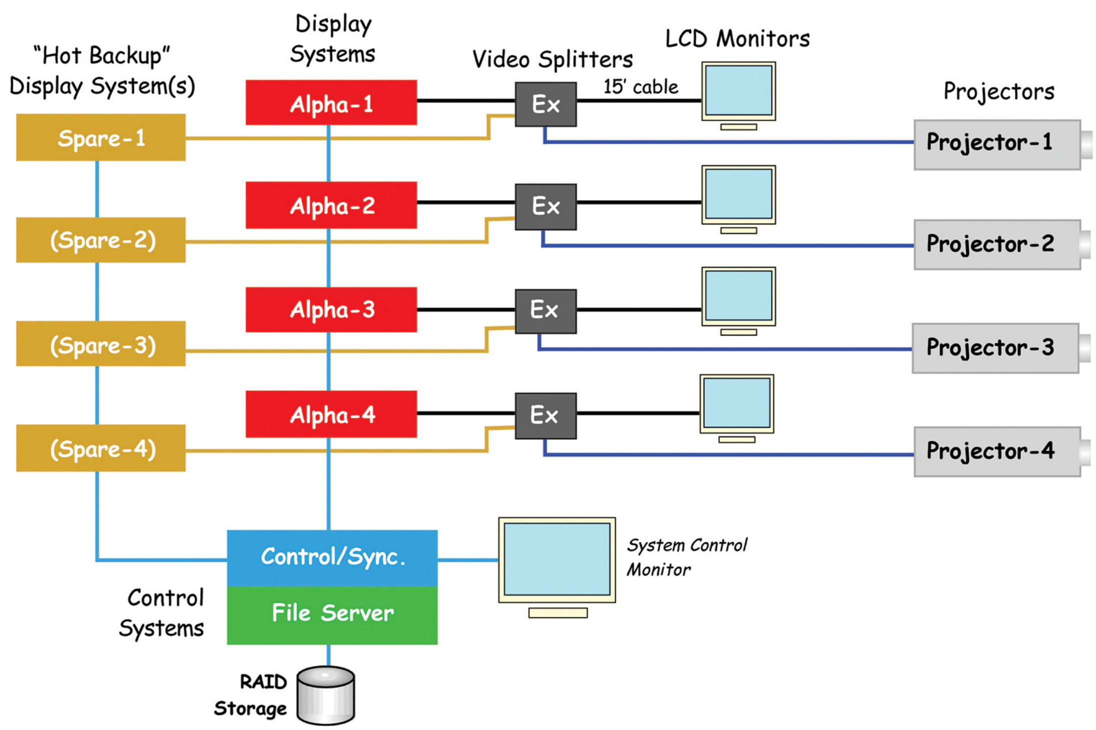


Figure 2: The basic Science On a Sphere™ system architecture.

The display computers are controlled through the Control/Synchronization computer, which is in turn controlled through the user interface. The user interface is accessed from the System Control Monitor, a wireless 802.11b PDA interface, or the installation's show floor control system. Other remote control options are under development.

Data streams can be created using sosrender on the Control/Synchronization computer, or another development node, then stored centrally on the File Server. The data is then distributed to the internal hard drives of each display computer. The actual data stream being shown is read directly from the display computer drives.

The video output from each display computer is typically routed through a video splitter. One of the splitter outputs is connected to a projector, the other to an LCD monitor. The four monitors are typically located in a control room and are used to verify that the output video feed to each projector is the correct image, is animating properly when verifying a newly loaded display product, during troubleshooting, or when running the system from the control room where the operator cannot see the sphere itself. The four monitors should not be needed during normal remote system operation.

The system uses off-the-shelf video projectors with standard projection lenses. The recommended video projectors have the correct angle of projection to properly cover the sphere from the required projection distance. They also come with the capability for a show floor control interface. Other projectors can be certified for use with the system. It is recommended that only projectors that have received prior certification by the Forecast Systems Laboratory (FSL) be purchased for the system.

FSL will work with individual installations to configure their system to meet their specific needs, including custom racks, alternative monitor displays, and custom show control interfaces.

Example Installations

Figure 3 illustrates the basic, or recommended, Science On a Sphere™ system. It represents, when purchased without the backup computer, the minimum number of components needed for the system. The Forecast Systems Laboratory does not recommend purchasing the system without a back up display computer, but this is dependent on the installation's risk tolerance. If purchased with the recommended configuration, the system comes with six PC-class computers. These are mounted and the system is configured in a single computer rack.

In this configuration, when a backup is necessary due to maintenance or an unscheduled situation, the affected display computer is manually disconnected from the related video splitter and the spare computer is connected in its place. The backup computer is configured to function as the replaced computer, and the system is brought back on-line.

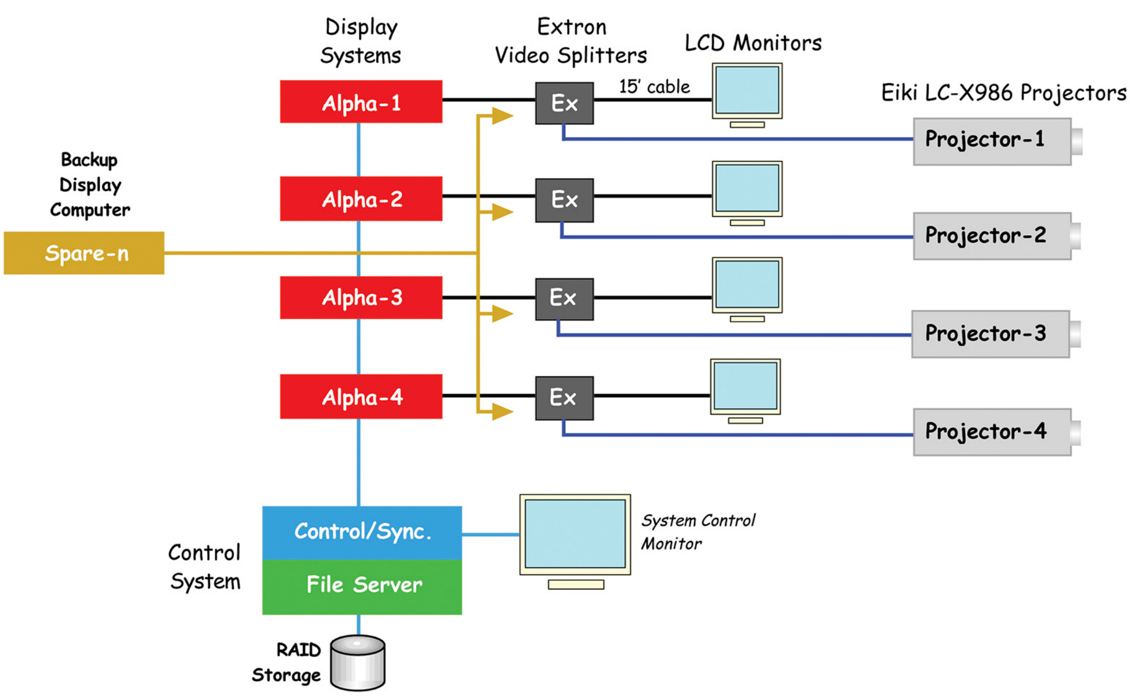


Figure 3: The basic recommended Science On a Sphere™ configuration.

Various switching systems are available to facilitate the failover to the backup system. The RAID drive shown connected to the File Server – Control/Synchronization computer in Figures 2 and 3 is also optional. FSL has determined that a RAID is no longer necessary; a standard high-speed internal drive serves well in this capacity.

FSL has also developed a ten-computer system. The ten-computer version, illustrated in Figure 4, adds a Rose Multi-Video Switch to the basic system architecture. This offers the advantage of immediate switchover to a full set of back up systems in case of maintenance or component malfunction. This configuration provides the maximum reliability for installations requiring uninterrupted streaming display in high a visibility environment.

This configuration also offers the potential of backing up the control/synchronization computer by switching its function over to the file server computer.

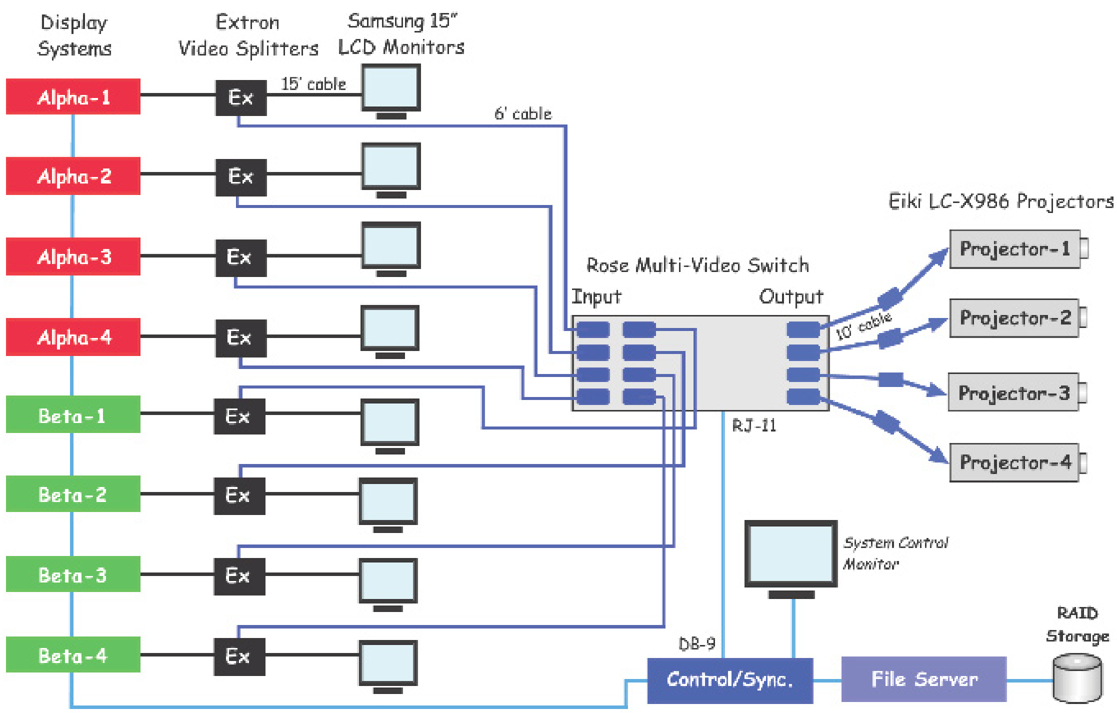


Figure 4: The physical hardware components for a 10-computer version.

3. Site Specifications

This section covers installation parameters for Science On a Sphere. Once the system is installed, this section should be needed only for troubleshooting reference.

System Geometric Parameters

The illusion of a body floating in space is achieved only when the system's geometric specifications are precisely followed. Alignment of the four projectors with the sphere requires a very tight geometric tolerance. The more accurately the following geometry is set up initially, the easier the alignment process becomes both the first time and throughout the life of the installation.

1. The sphere itself should be at the optimal viewing height for the installation. The Forecast Systems Laboratory (FSL) has found that 52 inches (1.32m) from the viewing floor to the base of the sphere works well for most circumstances. Positioning the sphere lower can result in viewers more easily occluding the projectors. In practice this is self-correcting, most viewers move out of the way of the projectors when they discern that their head is in the way, but 52 inches (1.32m) means that average height viewers must be quite close to the sphere to cast a shadow.

2. The sphere is suspended using three wires for stability. The suspension geometry cannot be too wide or narrow or the installation runs the danger of introducing instability to the sphere, which could be problematic for maintaining proper alignment. An example installation description and geometry are provided the System Setup chapter.

3. The projectors must be located exactly 90 degrees apart in an axis that passes exactly through the center of the sphere (as viewed from above, see Figure 5 on the next page).

4. The projectors lens must be at the same height as the sphere's equator.

5. The projector lens nodal point must be as close to 6.61 times the radius of the sphere away from the center of the sphere as possible. In practice, measuring from the front of the lens is sufficient. For the 68-inch (1.73m) sphere commonly provided, this puts the front of the projectors' lenses 224 3/4 inches (18.73 feet, or 5.71m) from the center of the sphere.

Site Preparation and Characteristics

As illustrated in Figure 5, the minimum floor space required to stage the 68-inch sphere is 30′ x 30′ (9.144 x 9.144 meters). The minimum height is in the range of 12 feet (3.66m): 4 feet (1.22m) to the bottom of the sphere, just under six feet (1.73m) for the sphere itself, and a minimum of about two feet (.61m) to allow the three-wire suspension system to spread sufficiently from the top of the sphere to assure stability.

Stability of the staging area itself is another significant design consideration. Stable reinforced concrete floors are desirable. A concrete slab floor directly poured on the earth itself is ideal. Any area prone to significant vibration or flexing, due either to impact (such as heavy automobile or train traffic) or temperature fluctuations, can cause the alignment of the projectors with the sphere to slip out of true. Though projector alignment, once the basic set-up is complete, is not generally a lengthy task, having to spend 10 to 20 minutes on this several times a day is disruptive and can be wasteful.

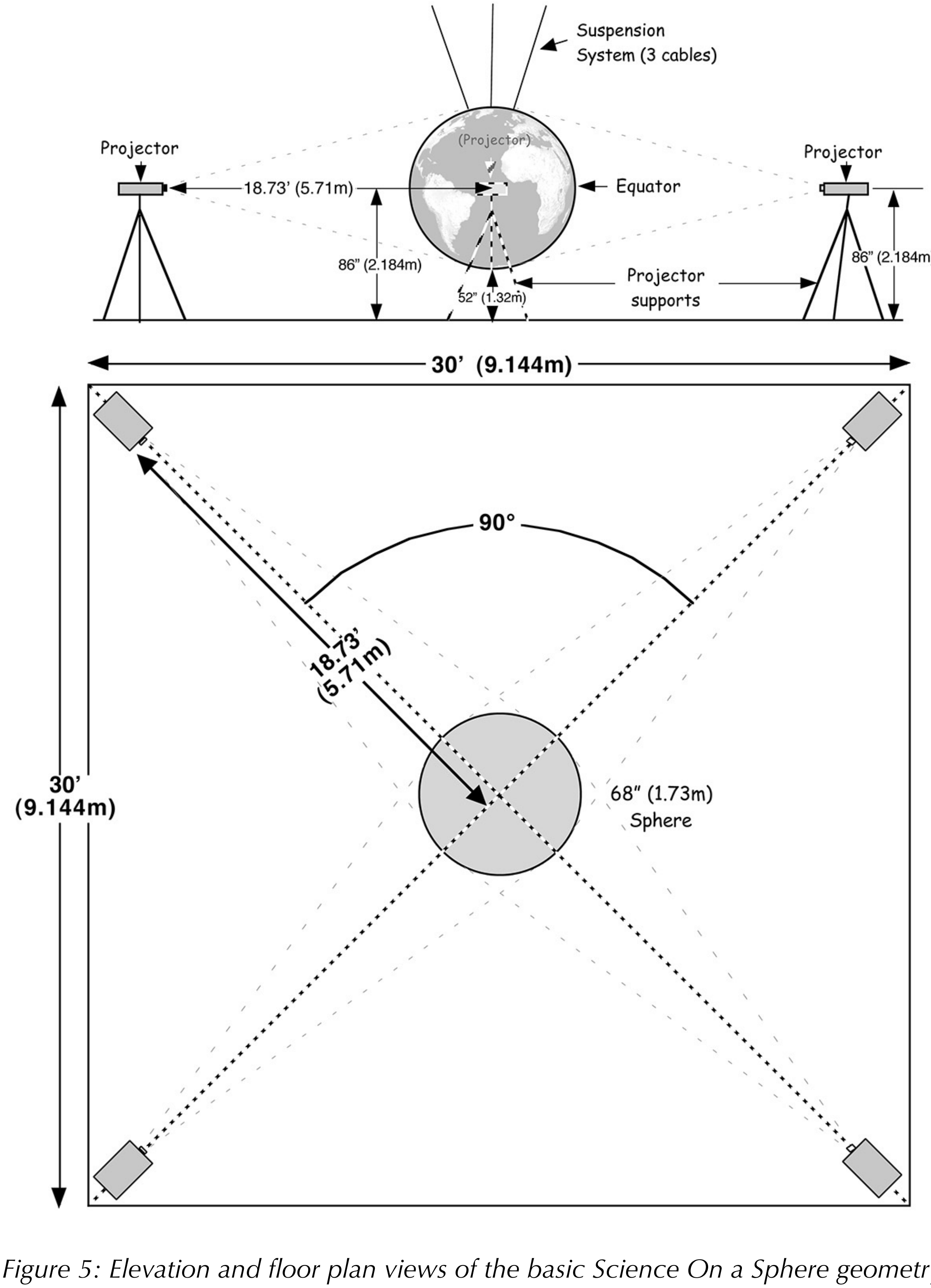


Figure 5: Elevation and floor plan views of the basic Science On a Sphere geometry.

Having the alignment slip during a presentation is especially problematic.

Ambient temperature stability can be critical, depending on the construction of the support structure. If the sphere is suspended from a stable ceiling, and the projectors rest on a stable floor, temperature control is less critical. If the sphere is suspended from a structure with a high coefficient of expansion, such as the aluminum structure FSL uses for its portable system, temperature stability becomes a requirement. The steel wires that hold the sphere have a relatively low coefficient of expansion. They should be relatively stable in fluctuating temperatures, unless the sphere is suspended from a very high ceiling.

Another factor with the potential to affect the stability of the sphere is HVAC plenums. The sphere developed for FSL is relatively light, weighing less than 50 pounds (22.7kg). A high enough velocity air stream directly impacting the sphere has the potential to introduce harmonic movement. Care should be taken to route air streams so that they do not directly impact the sphere.

In presentations without a docent available to control visitor traffic, it is important that the design of the display area be set up to deny visitors the easy opportunity to touch the sphere. It is the experience of FSL that viewers of Science On a Sphere often believe the presentation to be a holographic image, and when unattended have the tendency to try to verify their belief by touching the sphere. In addition to adversely affecting the sphere's stability, repeated contact can dirty the sphere's reflective surface to the point where repainting it becomes necessary.

As with any presentation, the surrounding environment is crucial to the enjoyment and effectiveness of the display. Science On a Sphere uses very bright video projectors (the recommended projectors put out 3300 lumens), enough to assure an engaging presentation in environments that have a reasonably high level of ambient light. Science On a Sphere is, however, more effective the darker the ambient surroundings are. The illusion of a planet in space, for example, is more dramatic if the area around the sphere has few distractions and is relatively dark.

Placing "black mirrors" (sheets of glass with black, none-reflective backing) in locations where reflections of the sphere are visible from the display floor creates an interesting effect.

While a reasonable amount of diffuse ambient light has little effect on Science On a Sphere, the site must be designed with no specular light sources that can reflect off the sphere, such as a direct shaft of sunlight. Any point source of light that impacts the sphere directly will detract from the presentation. This includes reflected light as well.

The computer system for Science On a Sphere must be in a temperature-controlled environment. No extraordinary steps need to be taken beyond what is customary for rack-mounted PC-class computer systems.

In order to assure system updates, timely remote troubleshooting and diagnostics, and a timely feed of NOAA data products if these are used by the installation, the system arrives ready to be connected to an Ethernet network. FSL recommends network speeds comparable to a DSL or broadband connection. A dedicated T1 or faster connection, while desirable, is not generally required.

4. System Set-up

This section covers the installation procedure for Science On a Sphere. Since every site is different, and applications vary, the deliberately generalized descriptions are followed by examples of specific site parameters. Any significant variations from the parameters in the specific examples can require recalculations. FSL support staff is happy to assist with any such calculations, and to help with any site customization issues.

The Science On a Sphere computer system arrives as a fully configured rack-mounted system from FSL. Connection points for the video projectors and monitors are clearly marked and accept standard video connections. Likewise, the mouse and keyboard connections are also marked. The system software is preinstalled at FSL, and updates from FSL can be implemented over the Internet.

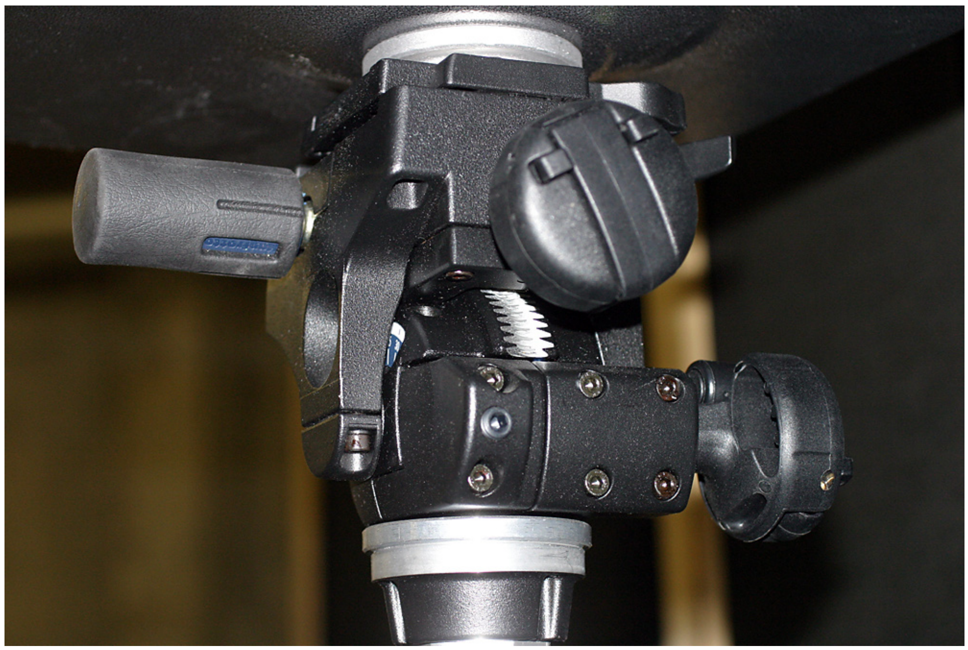


Figure 6: A geared tripod head.

Projector mounts must be adjustable on all axes, pitch, yaw, height, and sweep (side-to side pivot), in order to provide enough leeway to properly align the projectors with the sphere. Fine adjustment control is crucial. Distance from the sphere, if properly set up initially, should not need to be adjusted during the life of the system. FSL uses geared tripod heads on stable, height-adjustable mounts to provide this capability.

The basic geometry of the setup has been discussed. Suspending the sphere is installation-specific, but an example is included here for illustration.

Example Sphere Suspension

The following dimensions are based on creating the proper sphere-wire suspension angle from a 20-foot (6.1m) high reinforced concrete ceiling.

The sphere is suspended from three eyebolts mounted directly in the ceiling. Three suspension wires allow the sphere to find its own stable plane. As mentioned, the angle of the suspension wires must be just right. If the angle of the suspension lines from the sphere to the ceiling is too acute, the sphere can be susceptible to vertical instability (bouncing). Too steep an angle can make the sphere susceptible to pendulum instability (swaying).

To determine the eyebolt positions, first locate the exact desired position of the center of the sphere and mark it on the floor. The eyebolts should be mounted at three equally-spaced points, each 56″ (1.42m) out from the sphere center point, as shown in Figure 7.

One way to establish these three equidistant points is to pick the first point 56″ (1.42m) from the center point, and mark it on the floor. This corresponds to the lower-left eyebolt location in Figure 7. Then draw, or snap, a line on the floor through both the center of the sphere and this first eyebolt location, extending the line well beyond the sphere center on the other side. At a point 28″ (.71m) further out from the center, establish a right angle from this line and snap a second line on the floor perpendicular from the first, as shown. Measure 48 1/2″ (1.23m) out from the intersection of the first line in each direction along the second line to position the second and third eyebolt locations.

To verify the position of these last two eyebolts, measure their distances from the first eyebolt. This distance should be 97″ (2.46m). An error of an inch (2.5cm) or so is probably allowable here.

After marking the eyebolt positions on the floor, use either a laser level or plumb bob to find their actual locations on the ceiling. The eyebolts are installed according to generally accepted procedure. It is a good idea from a safety standpoint to use eyebolts considerably stronger than those needed to support a static 50-pound (22.7kg) load to account for lateral or vertical stress on the sphere due to impact or other physical contact, or in the case of a prone area, earthquakes.

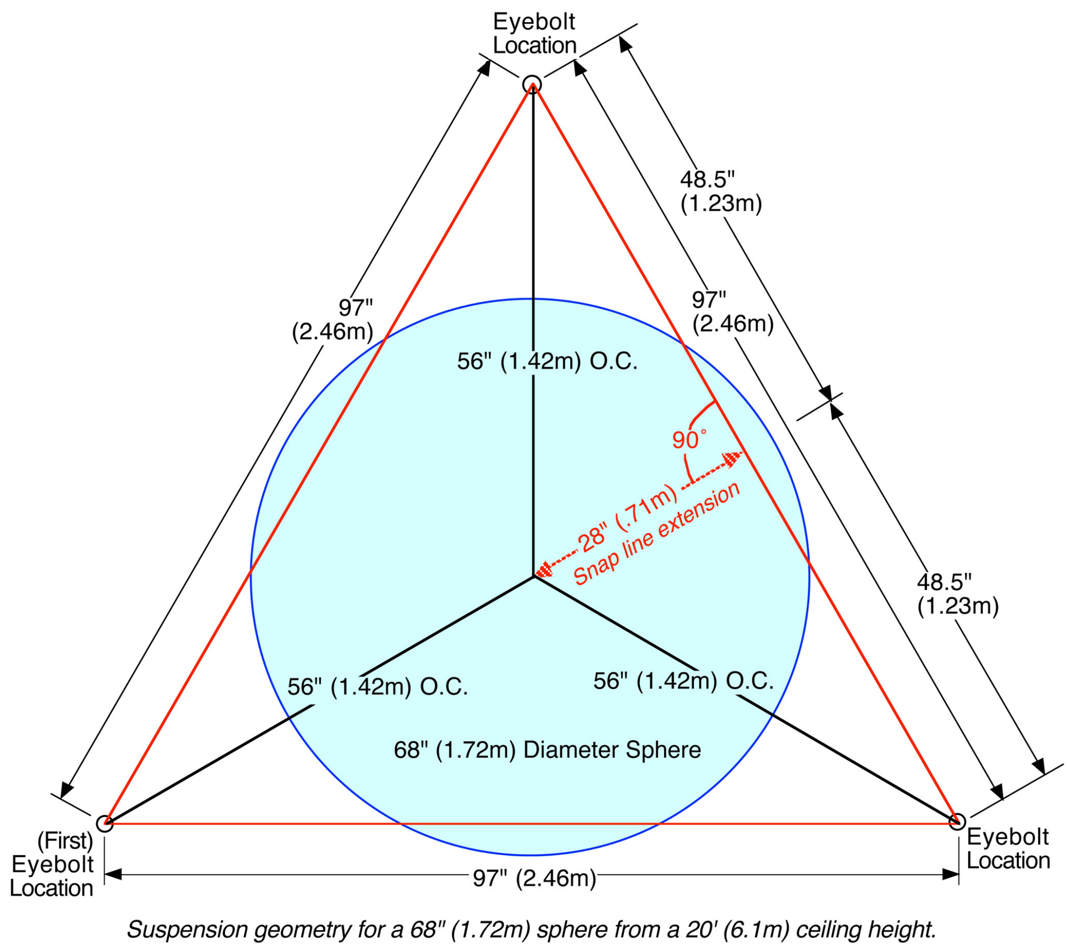


Figure 7: Example ceiling suspension geometry.

5. System Alignment Guide

It is anticipated that FSL staff members or contractors familiar with the system alignment procedure will be involved with the initial system installation and alignment. The system alignment typically needs fine-tuning on a regular basis, the frequency of this depending on the stability of the installation and the environment, and the occurrence of interference with the system from patrons or operator accidents.

The following description first covers the general approach to initial system component alignment. It is followed by a summary of the steps needed for regular system alignment maintenance.

Initial setup

The more precisely the components are aligned during the installation procedure, the easier the projector alignment will be every time it is done during the life of the system. FSL staff has discovered that one relatively uncommon tool in particular has proven indispensable to assure proper initial system alignment, and that is a planar laser level, such as the one shown in Figure 8.

This level projects a laser beam out of the hole in the front of the black structure pointing toward the viewer in the front of the level. The entire end of this small structure spins at a variable rate, and a second, sweeping, beam projects out of hole on the side of the structure. This hole is shown in Figure 9.

Figure 8: A planar (spinning) laser level.

Notice the built-in spirit (“bubble”) levels. The laser level can be adjusted on all of its axes to be completely level. This becomes useful later in the process.

The planar level therefore creates a pattern where a single line emerges perpendicular to the circular sweep of the level. If the level is positioned as shown in Figures 8 and 9, it creates a vertical sweep with the spinning laser, and a straight beam 90 degrees off from both sides of the vertical sweep

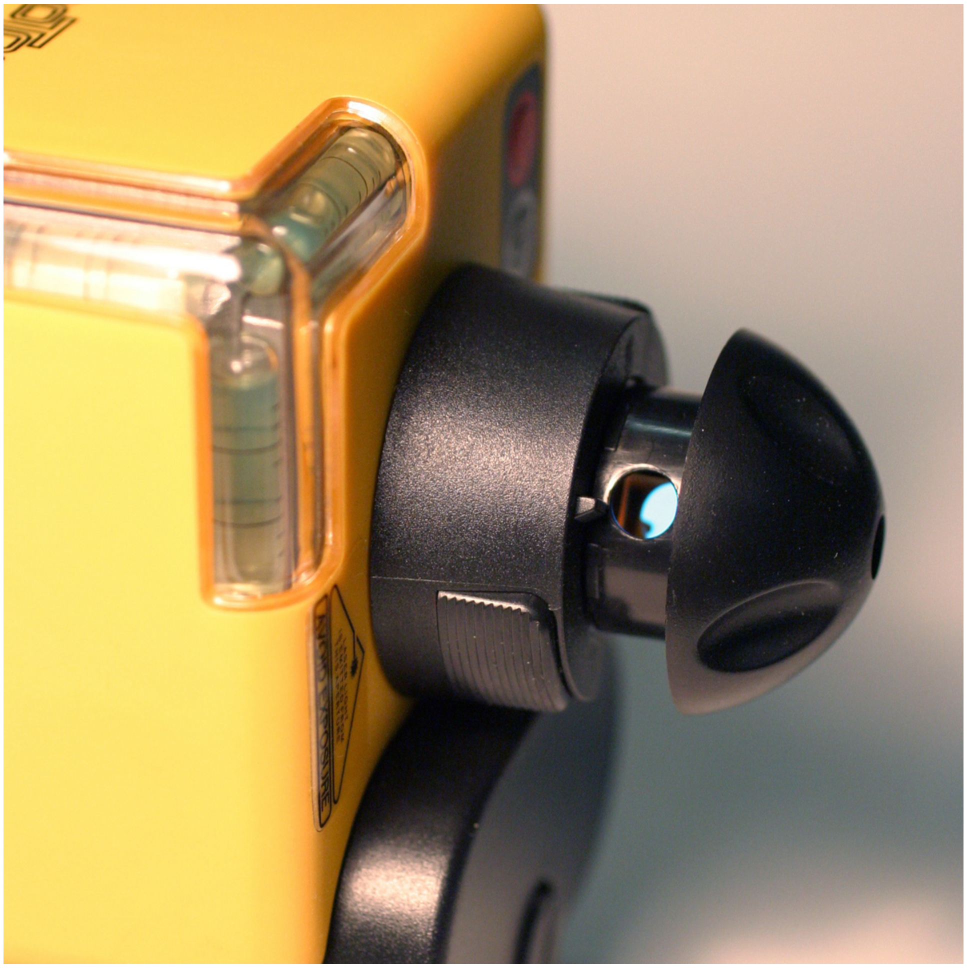


Figure 9: The side projection hole on the spinning tip of the level.

out the top of the spinning structure. If the level is positioned dead center under the sphere, any three projectors can be accurately positioned 90 degrees apart from each other. By turning the level 180 degrees, the fourth projector can be accurately positioned as well.

The level can also be positioned with the sweep moving horizontally. This is useful to assure that all of the projectors are positioned at exactly the same height, and that they are positioned precisely at the sphere's equator. The laser sweep should track precisely through the center of the front of the lenses of each projector as it sweeps across the equator. Because the sphere blocks the level, a maximum of three projectors can be aligned with each other at a time. The alignment of the fourth projector can be continued around the sphere with three previously aligned projectors to verify the alignment consistency. The equator can be further verified by projecting the proper alignment pattern on the sphere. More on that below.

If FSL is involved in the initial Science On a Sphere set up, FSL brings a planar level for the process. If the customer anticipates setting up Science On a Sphere in multiple locations, it is recommended the customer procure a planar laser level.

Projector Alignment with the Sphere

Projector alignment is crucial to the proper function of Science On a Sphere. If any of the alignment axes are off, even a minuscule amount, the convergence of the images between the four projectors will not be good enough to provide the illusion of a seamless image. Projector alignment is part method and part practice (or art). Experienced technicians can align the system in less than half the time of most novices.

Video projectors typically come with the capability to shift the projected image. This way, a presenter can place the projector on a table and have the image shifted upward to be visible over the audience's heads. For this application, however, the projection shift must be as close to zero as possible. In other words, the projection beam should be coming out of the lens as close to level with the projector itself as possible. If it does not, any change in the zoom focal length causes the equator and other latitudinal axes to shift up or down, making proper alignment much more difficult.

Before placing the projectors on their adjustable mounts, it is a good idea therefore to place all four of them on a flat table, equidistant from a flat projection wall, and attempt to eliminate all projection shifts. It is also a good idea to make the projected image size and level as close to identical for all four projectors as possible.

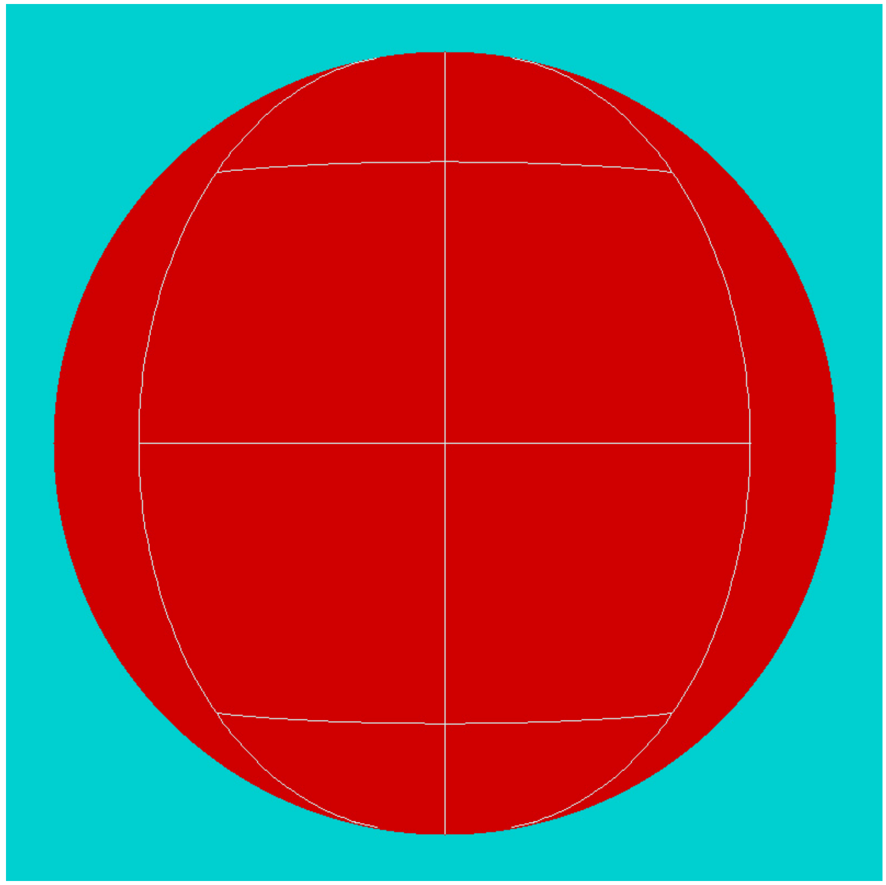


Figure 10: The "Circle-Grid" projector alignment pattern.

Once this step is done, the projectors can be mounted onto their adjustable platforms. Connect the projectors to the system, turn the system and projectors on, and from the user interface select the "Circle-Grid" product. This projects a stationary image that looks like Figure 10.

Follow this procedure for each of the projectors:

- While projecting the Circle-Grid pattern, zoom the image in or out so the red circle covers the sphere, and only the sphere, and covers the sphere as evenly as possible. Then use the mount adjustments to properly center the circle pattern. The edge of the red circle should be just tangential to the sphere where the coverage falls off at the sphere's sides, top, and bottom. In other words, the circle pattern barely touches the blue boundary of projector illumination, resulting in a bit of purple fringe uniformly showing around the entire red circle.

- The intersection of the central meridian and equator should then be in the center of the sphere when viewed from the projector.

- To verify that the projection shift is zero, zoom the image in and out while watching the equator. If the equator rises or falls, the shift is not zeroed out and must be adjusted. The mount height needs to be adjusted after tweaking the shift.

- Next, set the planar laser level on the ground directly between the projector and the center of the sphere such that the vertical sweep of the level runs up the sphere on one side and through the center of the front of the lens on the other side. Make sure the axes of the level have been centered using the bubble level guides on the laser level. This now gives an objectively vertical line against which to align the projected central meridian. Adjust the yaw of the mount accordingly. Do not adjust the yaw further during this procedure.

- If the alignment is not converging later, come back to these steps and repeat the procedure to this point.

Now with all four projectors displaying the Circle-Grid pattern, align the equators to each other by adjusting the mount up and down using the fewest possible number of adjustments. If the vertical alignment was correctly established using the laser level, the individual equator lines should all be horizontal at this point, and therefore only up and down adjustments should be needed to align all four equator line segments with each other.

Left and right mount centering can be adjusted and verified by converging the right and left edge meridians with the corresponding meridians on the adjacent projectors. When properly aligned, the edge meridians appear as a single vertical line where the projected images overlap.

At this point in the process, some of these adjustments are compensating for slight errors in the initial alignment procedure, and the process becomes more of an art than a science.

For each individual projector, the following is a set of symptoms and solutions. Each solution also needs to be considered in the context of how the adjacent grid lines are displaying:

Symptom: The lines diverge at both poles.
Cause: The image is too large.
Solution: Zoom the image smaller.

Symptom: The lines converge past each other at both poles.
Cause: The image is too small.
Solution: Zoom the image larger.

Symptom: The lines diverge at the North pole, but converge at the South pole.
Cause: The image is too low.
Solution: Tilt the projector up.

Symptom: The lines converge at the North pole, but diverge at the South pole.
Cause: The image is too high.
Solution: Tilt projector down.

Symptom: The lines veer to left at both poles.
Cause: The image is too far to the left.
Solution: Swing projector to the right.

Symptom: The lines veer to right at both poles.
Cause: The image is too far to the right.
Solution: Swing projector to the left.

6. Creating Science On a Sphere Visualizations

General Description

Science On a Sphere content can consist of any information suited for spherical display. NOAA concentrates on visualizations related to Earth systems. Examples from the Science On a Sphere media library include geophysical, atmospheric, and oceanic data, model simulations, weather forecast data, and visualizations of outer space objects such as Mars and the Sun. NOAA software provided with the system, sosrender, converts any type of properly prepared image data, either a single image or a time sequence of images, into Science On a Sphere-ready visualizations.

This capability provides an opportunity for organizations to display their global data on Science On a Sphere. Possibilities include population growth through the centuries, economic output, disease spread, agricultural output, trade routes, and so on.

It is a relatively straightforward procedure to create visualizations for Science On a Sphere, if one has access to appropriate data and experience with using image processing tools. This is a task best performed by someone with knowledge of the data, and experience with image processing packages like Photoshop. More advanced visualizations may require the experience of a visualization or graphics designer.

Content Creation and Input Formats

Content creation for Science On a Sphere is done in phases. Data is collected and combined into a global image or a sequence of global images.

The coordinate system of the input data is a simple latitude/longitude grid. This is sometimes called an equatorial cylindrical equidistant map projection (or simple cylindrical projection, or Plate-Caree projection), and is a convenient format for generating scientific and other data. See Figure 11. The top and bottom of the image corresponds to the North and South poles, respectively. Latitude progresses uniformly from one pole to the other. The left and right edges of the image correspond to an arbitrary line of longitude (typically 180 degrees), and longitude progresses uniformly throughout the image from left to right (West to East).

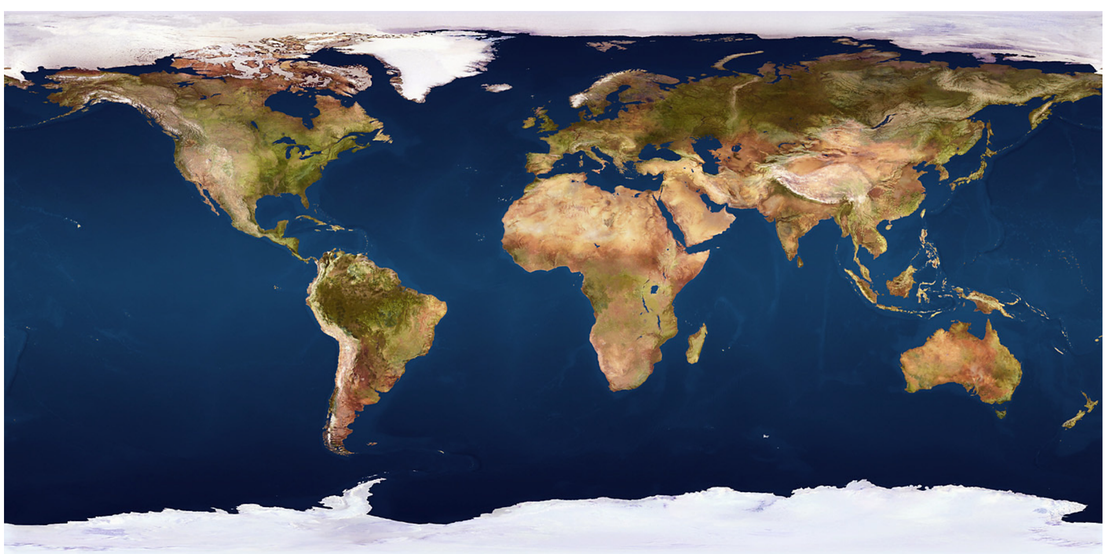


Figure 11: An example of an equatorial equidistant cylindrical projection map.

The image has to be in a global, latitude-longitude projection in which the image is rectangular with a 2:1 aspect ration (twice as wide as high). The exact center of the image is at latitude 0 degrees and longitude 0 degrees. From the center of the image going east, the lines of longitude vary from 0 to 180 degrees. Going west they vary from 0 to 180 degrees. This gives the image an east-west size of 360 degrees.

Correspondingly, going north from the center, the lines of latitude vary from 0 to 90 degrees, and 0 to 90 degrees going south, giving a total height of 180 degrees. For example, if the image were 360 pixels wide by 180 pixels high, each pixel maps exactly to an integral latitude-longitude position, with pixel 180, 90 being exactly at the center of the image (i.e. 0 degrees latitude, 0 degrees longitude).

In line with NOAA's mission of studying the oceans and atmosphere, Science On a Sphere has traditionally been used to display Earth systems data. However any data that maps well to a sphere is ideally suited for Science On a Sphere visualizations. Maps of the Earth abound on the World Wide Web, and are easily created with off-the-shelf GIS and visualization packages. In addition, beautiful, pre-made visualizations can be purchased from companies. The 600 million year plate tectonics visualizations that the Forecast Systems Laboratory shows is an example of purchased data rendered using sosrender.

Sosrender takes as input these simple, rectangular maps, on an equally spaced, latitude-longitude grid. The input and output file formats are one of any of the commonly used image formats, including JPEG, TIFF, and PNG. The color depth of the output images is currently restricted to 16-bit color depth. Image size is important; good visualization results can be achieved with base input images that are at least 3000 pixels by 1500 pixels, however most of the data FSL uses as base images are 4000 x 2000 pixels or greater.

An image created on a lat-lon projection is processed through sosrender to create the final visualizations. While the base input maps can be created with any package, the final phase of rendering must execute on a Linux system (similar to the Science On a Sphere computer systems).

There are two primary ways to create Science On a Sphere visualizations:

- Simple rotating animations: Use a single, base image as input and render the image into a sequence of frames to create a rotating globe. One input image ends up creating more than a thousand Science On a Sphere images.

- Time sequence animations: Use multiple base images and render each image into a Science On a Sphere ready visualization, which can be animated through the time sequence. The globe usually does not rotate in this case. The number of frames in the final animation is equal to the number of input frames.

After the final image scene is rendered, a few scripts are updated to tell the system about the new data and it is ready to use on Science On a Sphere.

In summary, here is a short outline of the steps required to create Science On a Sphere media with a simple example of just a World map (the map can have anything on it):

- Start with a base map of the world in a simple latitude-longitude map projection;
- Add any other supporting data to this image using your favorite processing package (Adobe Photoshop, Imagemagick, Gimp, etc…);
- Save the image off as a high quality JPEG;
- Transfer the image to the Science On a Sphere file server;
- Run the sosrender against the image;
- Wait for rendering to finish;
- Register the new data set with the system;
- Display the new visualization.

SOS Render

Sosrender is the program that converts one or more image files of the entire earth – or any dataset properly prepared, as described above - into a set of files ready to be displayed on the Science On a Sphere system. This is done by modeling a sphere in the OpenGL 3-D graphics package, wrapping (texture-mapping) the input files onto the sphere, viewing the resulting sphere as seen by each of the four projectors, then dumping a 2-D image for each projector. The image is also typically masked for smoother edge blending.

Input file formats

A variety of image file formats are accepted as input by sosrender including GIF, JPEG, PNG, and others.

Images with a 2:1 aspect ratio, as described, result in each pixel being the same number of degrees wide as it is tall. This results in complete coverage on the sphere. While recommended, this isn't strictly required, since the rendering software uniformly stretches any rectangular image to cover the entire earth. For sharpest image quality, FSL recommends an input file size of at least 1500 pixels high by 3000 pixels wide. If this high a resolution is not available, sosrender automatically interpolates the data to a higher resolution.

Modes of operation

Sosrender has two major modes of operation: rotation and time-series. In rotation mode, a single input image is wrapped around a virtual sphere and rotated, creating a set of output files that can be looped to create a complete rotation of the earth. The number of time steps for the rotation is specified by the -n input parameter.

In time-series mode, a number of sequential input files are specified. Each file is wrapped around the virtual sphere in the same position, and the resulting Science On a Sphere output files animate through the input view sequence, from first to last. Time-series mode is indicated by the absence of the -n parameter.

Post-processing

Once *sosrender* has created each output file, additional processing can be done by a post-processing script. A post-processing script is specified with the -p parameter. For example, FSL uses this post-processing to mask and dither the images, and convert them to jpg, by specifying -p addmask_dither_jpg.pproc.

Command-line arguments

If *sosrender* is run with no arguments, it prints a short help summary:

Usage:

```
sosrender [-s window_size] [-n #steps] [-b begin] [-e end]
          [-l lon] [-t tilt,x,y,z ] destDir srcFile
          [...srcfile]
```

-s window_size	Size of (square) rendering window. Default is 800.
-f file_prefix	Prefix for each rendered filename. Default is "frame".
-n #steps	Render a rotation with the specified number of steps. In rotation mode, only the first srcFile is used.
-b begin	Begin rendering at the specified frame (default is 1)
-e end	End rendering at the specified frame (default is 1)
-l lon	Specify the center longitude (west is negative). This longitude is centered between projectors 3 and 4.
-t tilt,x,y,z	Specify an initial tilt around an arbitrary axis. For a realistic earth tilt around the x-axis (between P3 and P4), try -t 23.5,1,0,0
-p script	Run post-processing script on each file. The script should read PPM data from stdin, and write a file named by the first argument to the script (changing the extension if appropriate).

The -s option specifies the size of the output file. This option should not be used for output intended for display on the sphere, but can be useful for limiting data size (and increasing speed) for various test scenarios.

The -f option specifies a file name prefix. By default, the prefix is "frame".

The -n option enables rotation mode, and specifies the number of time steps to render for a complete rotation. For example, a value of 1800 results in 1800 time steps for a complete rotation (each time step shifts the earth 1/5 degree).

The -b and -e options are used in rotation mode to specify rendering only a subset of the complete rotation. The -b option specifies the first frame number and the -e option specifies the last. Frame numbers start with 1.

The -l option shifts the center longitude meridian of every input image before rendering, by the specified number of degrees. Positive values shift to the right.

The -p option runs a specified post-processing file on each file created by sosrender. This is used to apply a mask and dithering if desired.

The -t option specifies a tilt to the earth after mapping the input file. The argument is a set of four comma-delimited values (no white space is allowed here). The first argument is the number of degrees to tilt. The next three arguments specify the x-, y, and z- components of a vector around which to apply the tilt. The z-axis is the North Pole, the x-axis points out the equator at the Prime Meridian, halfway between the P3 and P4 projectors, and the y-axis points out the equator 90 degrees east of the x-axis (experimentation can make this easier to understand). For example, a value of -t 23.5,1,0,0 creates an earth accurately tilting to the left as seen halfway between the P3 and P4 projectors.

Figure 12 shows the results of running the map shown in Figure 11 through sosrender.

Figure 12: The resulting four files after running Figure 11's map through sosrender.

This result was created using *sosrender* using the following command:

```
sosrender -n 4 . earthmap2k.jpg
```

This mode takes a single image and creates a rotation image sequence (in this case only 4 images). We would typically choose a number in the reange of 1800 for a nice, smooth animation.

The parameters specify:

-n 4 means, create four images for the rotation,

"." means put the output in the current working directory

earthmap2k.jpg is the texture map in the ECE projection, used for input.

Sosrender runs and creates a directory, "P1", in the current directory. It created four files named frame0001_P1.png through frame0004_P1.png. Sosrender can output directly to jpeg format files, and apply the mask.

7. User Interfaces

The Science On a Sphere user interfaces, and therefore this document, are still very much under development. Three basic interfaces are in development. These are:

Monitor Control - FSL currently uses the control-monitor interface, described in this chapter, for its demonstrations. Though simple and reliable, it requires two operators for a smooth docent-led presentation.

Show Floor Control - This interface is still early in its development. A brief introduction is included in this chapter. This section of the chapter will be updated rapidly as development continues on this interface.

Remote Control - The current version of remote control runs on a Palm Operating System PDA and uses the 802.11b Wi-Fi (Airport) protocol for communication with the computer system.

Monitor Control

Sometimes called the “Streaming Interface,” this is the simplest and most direct way to control the system. It is controlled using a mouse and keyboard, and the interface displays on the control/synchronization monitor. It offers the flexibility to quickly call up any of the loaded data sets for display with a minimum load time before animation becomes available, which lets a docent – and the system operator - respond quickly to the demands of the presentation.

The interface is also configurable. Specifications can be entered that cause the data stream to animate immediately upon loading or wait for operator input. Audio files can be associated with the data stream and started precisely when the animation begins. Other configurable parameters will be added as time permits and installations require.

Once the interface is started, the screen looks like Figure 13.

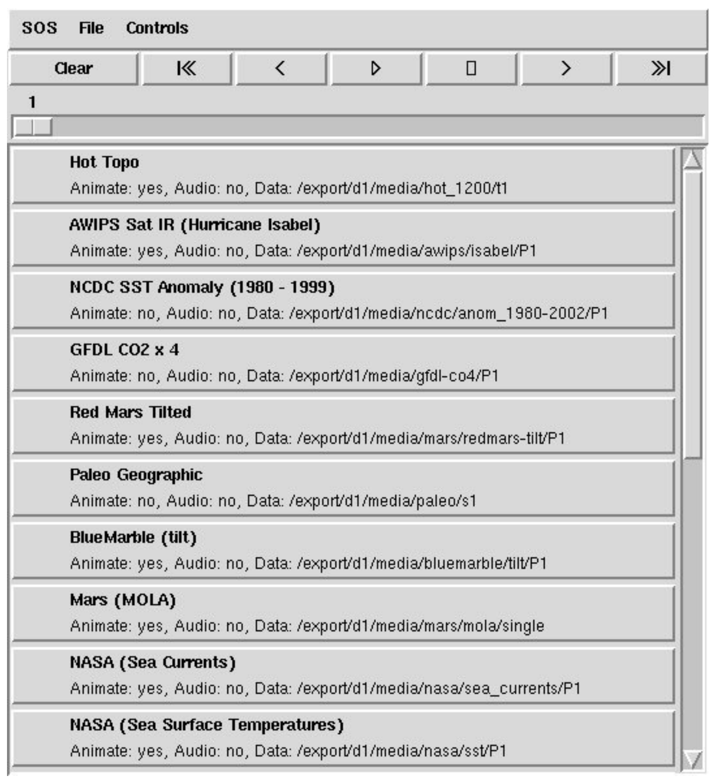


Figure 13: The monitor control interface as opened.

The operator then selects the data stream to be displayed with the cursor and left-clicks the mouse. The interface then changes color to indicate the data stream is loading, as shown on Figure 14.

Once the data stream is loaded, the selected stream changes to a green color on the interface, as illustrated in Figure 15.

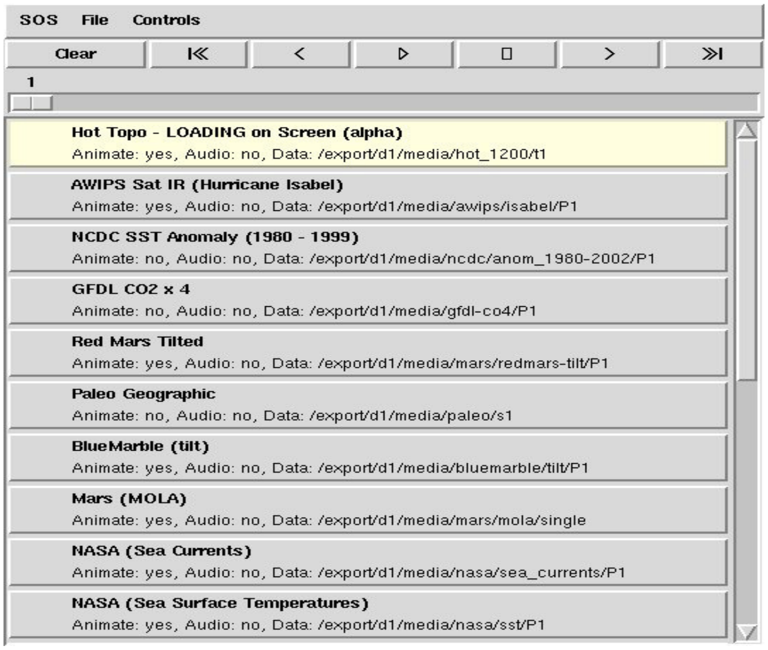


Figure 14: The "Hot Topo" data stream is loading.

Notice that in Figure 15, the slider located directly over the "Hot Topo" box has moved from "1" on the left to "970" toward the right. When the data stream is running the slider bar continuously moves from left to right. The slider is selectable, and can be used to control the animation directly.

The controls at the top of the interface mimic a typical CD player in use. The play and stop buttons do exactly what one would expect. The left arrow causes the data to animate in reverse if the stream is animating, or moves the stream back one frame (or several if the mouse button is held down) if the animation was stopped. The buttons with double arrows move the stream to its first or last frame.

To configure the monitor interface …
(content to be added here)

Show Floor Control Interface

In addition to controlling Science On a Sphere via the Monitor Control Graphical User Interface, it can be controlled remotely via a simple network protocol. This interface is intended to allow show control or other automation systems to control Science On a Sphere. This remote control capability is enabled or disabled from the sos_stream menus.

Socket Protocol

Science On a Sphere show floor control is based on a simple network socket protocol. To establish a control session with Science On a Sphere, the controlling program first connects to socket 2468 on the Science On a Sphere network controller host computer. For testing purposes, one can easily establish a telnet session to the control socket, and type commands interactively.

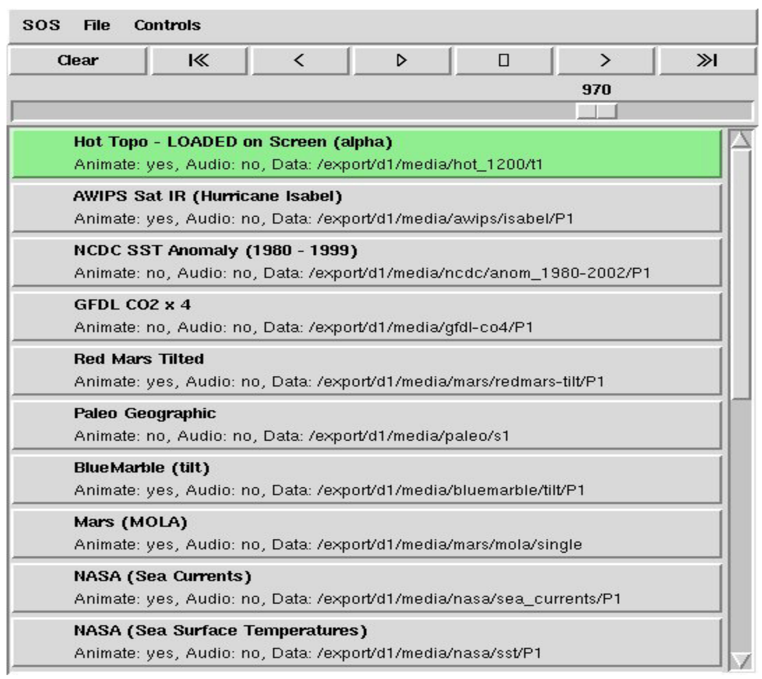


Figure 15: The "Hot Topo" data stream is loaded and animating.

Commands are sent to Science On a Sphere one line at a time. All commands are two-character mnemonic strings, with an optional numeric argument preceding the command.

Upon successful completion, every command except status requests returns a status line consisting of the single character ‘R’. Status requests return a one-line status value instead. An error status is indicated by the string Enn, where nn is a two-digit error number. A limited number of error conditions are returned. E04, for example, indicates an unrecognized command. Unexpected numeric arguments are ignored without feedback.

Science On a Sphere Commands

This protocol is modeled after the serial control protocol used by Pioneer® DVD players, but FSL make no claims of complete compatibility. The currently loaded Science On a Sphere playlist, with a set of clips, appears to the protocol as a loaded disc with a set of titles. The terms clip, title, and track can be considered interchangeable in the following description.

Optional numeric arguments are show in brackets.

Play
Command: **PL**
Resume or begin playing the current clip. If no clip is currently loaded, load and play the first clip in the playlist. Return status message as soon as playing begins.

Note: SOS will loop the currently playing clip indefinitely.

Still
Command: **ST**
Stop playing the current clip, while showing the current frame.

Step Forward
Command: **SF**
Step one frame forward.

Step Reverse
Command: **SR**
Step one frame in reverse.

Search
Command: **[location] SE**
Skip to a specified location, display it still, then return status. The location is either a frame or title, depending on the current addressing mode (the default is frame). If a location argument is not specified, 1 is assumed. Successful status is returned as soon as the clip is ready to be played.

Frame
Command: **FR**
Select frame-addressing mode, after which numeric arguments that specify a location are interpreted as a frame number within the current clip. This is the default addressing mode.

Title
Command: **TI**
Select title-addressing mode, after which numeric arguments that specify a location are interpreted as

clip number within the currently loaded playlist.

Title Number Request
Command: **[title] ?R**
In the Pioneer® protocol, this request takes no argument. If no argument is specified, return the currently loaded clip (title) number.

FSL has extended the original intent of this command to take a title number as an argument. If the argument is 0, return the number of clips (titles) in the current playlist. If the argument is greater than zero, treat it as a title (clip) number and return the clip name as shown by the sos_server user interface for that clip.

Frame Number Request
Command: **?F**
Return the current frame number.

Total Frame Request
Command: **?Y**
Return the total number of frames in the current clip.

Wireless Remote Control

Science On a Sphere can be controlled using a Palm Operating System PDA equipped with an 802.11b Wi-Fi (Airport) capability. The software, written by FSL, is supplied with the Science On a Sphere system. (content to be added here).

Appendix 1: Dataset Scripts

These narratives are intended to be read aloud while presenting some of the basic Science On a Sphere™ datasets supplied through NOAA. They are not intended to be comprehensive descriptions of these datasets. They can serve as a guide to a docent giving a live presentation to a group viewing Science On a Sphere.

1. Introduction

Welcome to the National Oceanic and Atmospheric Administration's Science On a Sphere. Dr Sandy MacDonald, who is the Director of NOAA's Forecast Systems Laboratory in Boulder, Colorado, invented Science On a Sphere. Science On a Sphere is a scientific and educational outreach system intended to help showcase NOAA's science in museums, science centers, and schools.

Science On a Sphere uses a six-foot (1.83 meters) in diameter white sphere as the screen onto which four video projectors project animated data. The sphere installed in Boulder, Colorado is made of ABS plastic, and constructed in the same pattern as a soccer ball. It weighs about 70 pounds, or around 32 kilograms. Other spheres in use with Science On a Sphere™ range in weight from an under-40-pound (18.1 kg) carbon-fiber sphere to a 230-pound (104.3 kg) fiberglass and resin version.

A bank of PC-class computers running the Linux operating system and custom software developed at the Forecast Systems Laboratory drives the system. Four computers drive the four projectors at any given time, streaming the data off of their internal hard drives in real time. Another computer acts as the controlling and synchronizing computer, and a sixth computer acts as the file server. Different computer configurations have been configured depending on the needs of different Science On a Sphere installations.

There are no actual moving parts to what you see here.

2. NGDC Topography and Bathymetry

This display is of the Earths' Topography and Bathymetry. This dataset comes to us from the National Geophysical Data Center, or NGDC, courtesy of Dr Pete Sloss. The data set is rendered in a color scheme that creates the illusion of three dimensionality when viewed through "phase shift" 3D glasses.

As you approach the display you see the heights of the earth over land, also called the *topography*, and the terrain of the earth under the oceans, also called the *bathymetry*. It is easy to remember which one is which, since bathymetry starts with a "bath"… Look at how much there is going on under the water in terms of undersea mountains and valleys.

There are a number of things that are interesting about this data. First, look at the middle of the Atlantic Ocean and notice the mountain range that extends down the whole length of the ocean. This is called the *Mid-Atlantic Ridge*. It is actually a continuous chain of active volcanoes, where new crust is being created all the time. This new crust is pushing Europe away from North America and Africa away from South America at the rate of about one inch, or two and a half centimeters, a year.

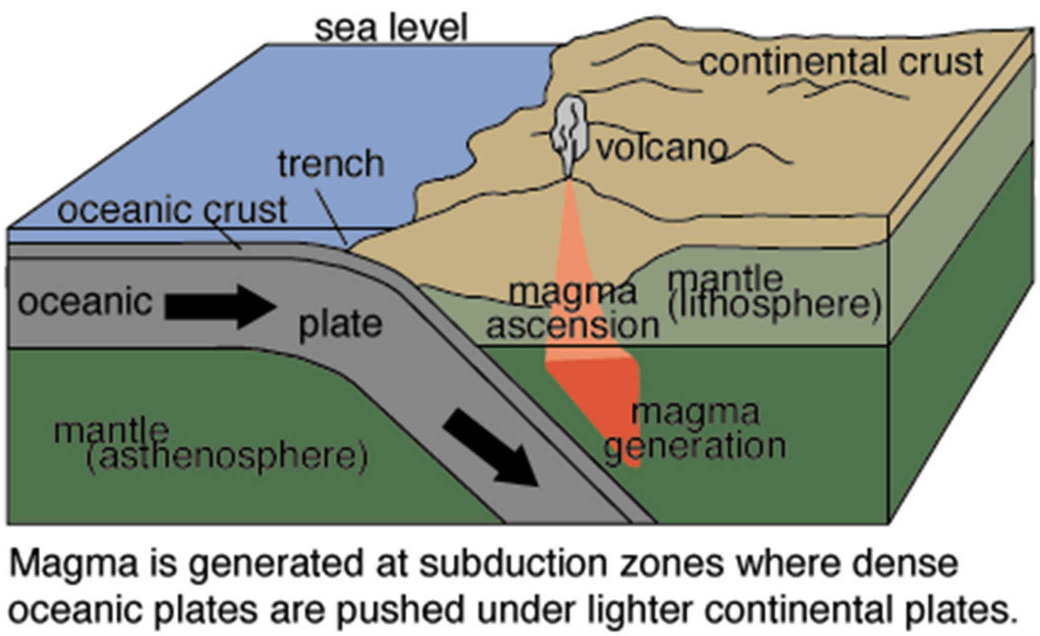


Illustration: University of North Dakota Volcano Website

So where does the old crust go when a continent is being pushed in one direction? Look off of the coast of Chile. That very deep trench you see there – called, very originally, the Chilean Trench - is what geologists call a *subduction zone*. These occur when one of the earth's pieces of crust, called a *plate*, is pushed into another plate. Something has to give, so often one of the plates dives – or subducts - under the other one. (Usually the younger plate is less dense and rides on top of the older plate.) The Andes Mountains are the direct result of this collision as the South American Plate crumbles as it moves over the Southern Pacific Plate. The friction caused by the plates running over each other can spawn volcanoes.

Now look at the other side of the Pacific Ocean. Just south of Japan there is another trench – also formed by a subduction zone - shaped roughly like a "D". This is the *Marianas Trench*, the deepest part of the Earth's crust. It's so deep that if you could pick up Mount Everest and turn it upside down and drop it into the Marianas Trench, there would still be over a mile (1.6 km) of water from the base of Mount Everest to the surface of the ocean. The Challenger Deep in the Marianas Trench is 35,813 feet, or 10,915 meters deep!

It is easy to spot the Himalaya Mountains just north of India, the highest mountain range on earth, as well as the Andes and our own Rocky Mountains.

On the other side of the Sphere is something completely different. Here on the dark side of the sphere you see the lights of the Earth at night, which comes from the polar-orbiting Defense Meteorological Satellite Program, or DMSP, satellites, courtesy of Chris Elvidge, also of NGDC. The data you see here is the result of many passes by these satellites, so we don't have to worry about clouds obscuring the image.

Check out the United States. See how the lights over the US show the paths of our interstate highway system? We have developed along these highways so heavily the last 30 years or so that their paths are now visible from outer space.

Japan is very well lit up and visible from space, as is South Korea. But look closely – North Korea is almost invisible! This points out the two things we can tell from the lights of Earth at night – population density, of course, but also economic development. There are a lot of people living in North Korea, but not a lot of money to leave the lights on all night. In sub-Saharan Africa we see the same thing, lots of people without a lot of money, so not many lights. The Nile Valley is very well lit up, on the other hand, as is the Riviera coast. Notice that all over the world, people do tend to live more along the coasts.

3. GOES Infrared Satellite Cloud Images

This dataset shows Infrared Satellite Cloud Images from GOES satellites**.** It shows the Earth stationary, with the data moving over its surface. This dataset is put together from a number of different geostationary earth-orbiting satellites, and covers the period in September 2003 when Hurricane *Isabel* was crossing the Atlantic and closing in on the United States.

The infrared sensors on the GOES satellites are sensitive to temperature, as you might expect, but cannot see through clouds. This is useful for meteorologists, since it gives them the temperature of the tops of the clouds. This can be a good indicator of the severity of a storm system. For example, look at the dark green colors in the middle of some of these cloud clusters. This represents temperatures in the range of 100 degrees below zero Fahrenheit, or –73.3 degrees Celsius, even though some of these storms are right over the equator! This means the tops of these clouds are very high up in the atmosphere, and that the storms under them are likely to be very strong.

Speaking of storms along the equator, notice that an intermittent line of storms circles the equator all around the world. This is what meteorologists call the *Intertropical Convergence Zone, or* ITCZ. Some of the storms that impact North America originate in this zone.

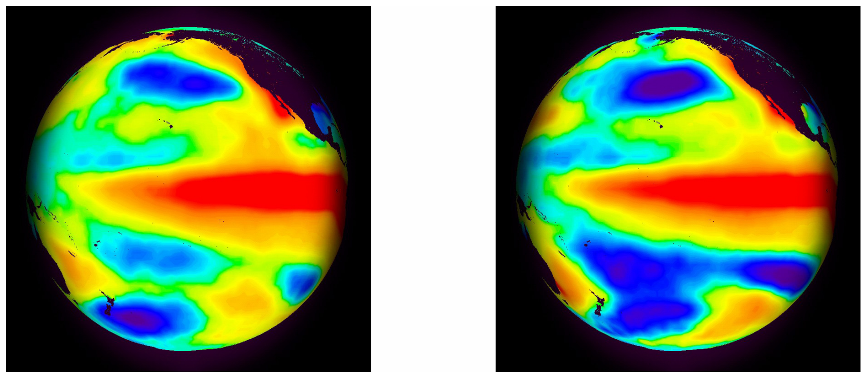
Now take a look at the northern Atlantic Ocean. See the smallish, tightly wound storm moving toward North America? That was Hurricane Isabel, which impacted the US around the North Carolina and Washington, DC area. Notice that while it was over the middle of the ocean, the storm was very tight with a clearly visible eye. During that time it was one of the strongest hurricanes we see, a Category 5. As it approaches North America, though, notice how the storm begins to widen out and break apart a little. Thankfully, it lost a lot of its intensity before it hit the US, and did not do near as much damage as it could have done had it remained as strong as it was while over the middle of the Atlantic.

4. 20 Year Sea Surface Temperature Anomalies

This next data set shows twenty years of sea surface temperature anomalies starting in the year 1980. This data comes to us from NOAA's National Climatic Data Center.

We are going to look for a phenomenon that occurs off of the South American Pacific Coast and well into the Pacific Ocean, one you've probably heard of occasionally in the news. That event is called *El Nino*. It can have a dramatic effect on the weather of North America, especially the West Coast.

The color scheme is pretty easy to follow; green indicates sea surface temperatures about where we would expect them to be. Cooler colors, such as blue and very dark blue, indicate cooler sea surface temperatures, and as you would expect, warmer colors reflect warmer temperatures. Lets start the animation, and stop it on the first significant *El Nino* event in 1982-83.



The 1997-98 El Nino: The left image is from December 5, 1997. The right is from January 25, 1998.

As you can see, it is not a subtle event. It extends thousands of miles out into the Pacific. But look at the coast of Baja California, and notice there is also pretty significant warming of the sea surface there as well. It turns out this is directly related to *El Nino*. *El Nino* affects the path of storms which come off of that Intertropical Convergence Zone we saw so clearly in the previous data set, causing these storms to track lower down the coast than they typically would. The churning of the sea surface caused by these storms suppresses the normally very cold California Current, and warms the warmer Davidson Current even more. Though visible here, it becomes even clearer in the biggest *El Nino* we've seen, which we'll show in just a minute. Let's move forward.

The opposite of the *El Nino* is the *La Nina*. As you would expect, this is a bloom of much colder than normal sea surface temperatures in the same approximate area of the *El Nino*, as you see here. Though *La Nina* has a pronounced effect on the climate of South America, its effects on North America do not seem to approach the intensity of *El Nino's*.

Now let's move forward to the 19997-98 *El Nino*, the strongest one on record. As you can see, it extends about as far into the Pacific as the 1982-83 *El Nino*, but it also extends much farther down the coast of Chile than the earlier event. But notice now the amount of secondary warming along the entire Pacific Coast of North America, starting in Alaska and extending past Baja California.

In October of 1997, those of you who lived in Denver at the time might remember waking up one morning to about three feet of snow – and a large number of tree limbs – on the ground. This unusual storm was in part a result of the change in weather patterns brought about by *El Nino*.

At the start of the year 2000 there was a mild *La Nina* underway, and we are currently experiencing a mild *El Nino*.

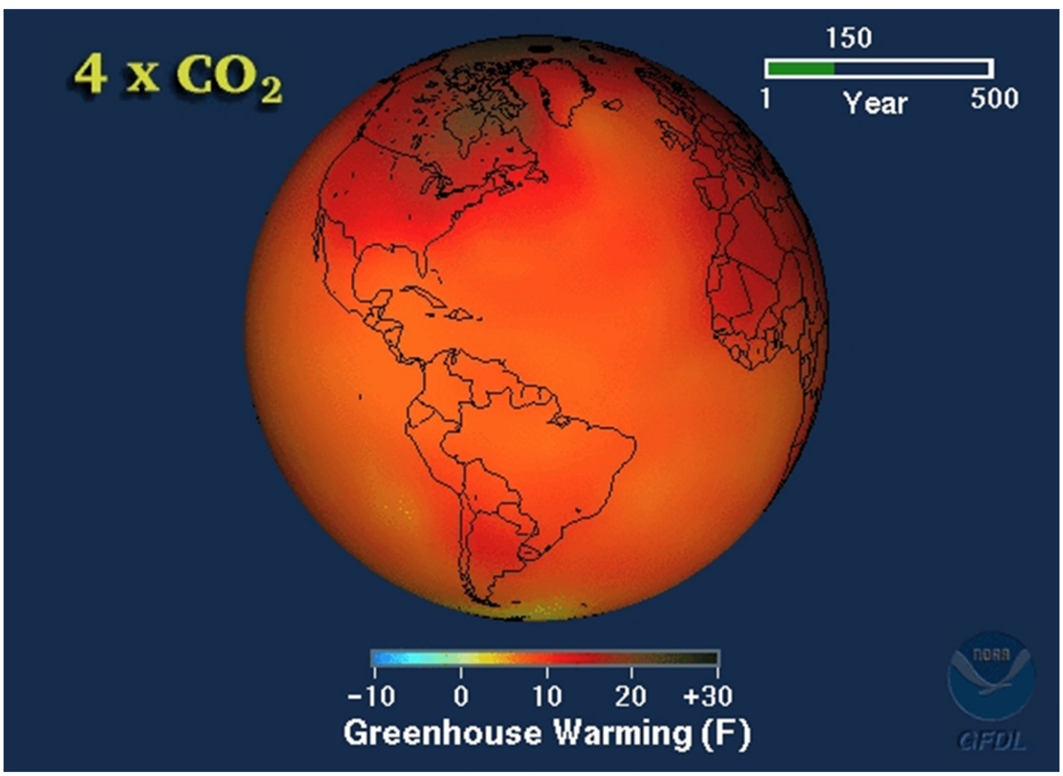
5. 500 Year Climate Model

Now we are going to look at something a little bit scary. We are going to see the results of a model that shows what another NOAA laboratory, the Geophysical Fluid Dynamics Laboratory, or GFDL, in Princeton, New Jersey, thinks may happen to the mean surface temperature of the earth over the next 500 years.

This model assumes that the amount of carbon dioxide in the atmosphere is going to increase at the rate of one percent per year every year for the next 140 years, which would quadruple the amount of carbon dioxide in the air over what it is today. The model then assumes we stop putting so much carbon dioxide into the air and that the amount stays the same.

At the start of the model, the green color means the mean surface temperature when this model was initialized in 2000, was about where we would expect it to be. Blue colors mean the temperature is a little cooler than normal, and the yellows and oranges mean the temperatures are a little warmer. Notice that in 2000, the southeastern United States was actually a little cooler than normal.

Once the animation starts, if you see a light red color, that means the surface temperatures are about five to ten degrees Fahrenheit, or 2.8 to 5.6 degrees Celsius, warmer than today, dark reds men ten to twenty degrees Fahrenheit, or 5.6 to 11.2 degrees Celsius, warmer, and if you see a black color the temperatures in that area are as much as *thirty degrees Fahrenheit, or 16.8 degrees Celsius, warmer* than today. Let's start the animation.



At about 100 years out the polar ice caps have completely melted. Yes, this means the shape of the continents will also change, but we don't show that here. Notice that after 140 years, even though the carbon dioxide levels stop increasing, the surface temperatures do not cool off. The earth heats up and stays hot.

Notice also that the Northern Hemisphere – like where North America is – heats up more than Southern Hemisphere – such as South America. The reason for this is relatively straightforward; there is more water in the Southern Hemisphere than in the Northern Hemisphere relative to the amount of land. Water does a good job of moderating temperature changes. Land heats up quicker and cools down faster than the oceans.

This model is one of the more pessimistic models. There are other models that do not show nearly this much warming. Those models assume that low and mid level clouds will increase as the planet warms up, and that this will keep the surface cooler than otherwise. This model, on the other hand, says low and mid-level clouds will burn off, like over Australia now, giving us a lot more surface warming.

Which model is right? Let's meet here in five hundred years and talk about it…

6. X-Ray Solar Image

Well, if that wasn't hot enough for you, lets take a look at an X-ray image of the Sun.

This dataset was put together from an x-ray sensor on board the GOES 12 satellite, and comes to us courtesy of the Space Environment Center in Boulder, Colorado. The x-ray senor shows the corona of the sun, which is much hotter than the visible surface of the sun. It does a good job of depicting solar storms, which are the white flashes you see here.

Yes, the sun does rotate. It takes about 27 days for the sun to make a complete rotation. Interestingly, the sun actually rotates faster at its equator than at its poles.

If this were the actual size of the sun, and this sphere is about six feet in diameter, how big do you suppose the earth would be in comparison?

The actual size of the earth would be about 5/8″ or 1.6 cm, or about the size of a United States nickel. It would fit comfortably inside any of these storms you see here – well, perhaps comfortably is not the right way to put that, since the entire planet would be vaporized almost instantaneously.

If this were the size of the sun, and the earth were the size of a nickel, to be the same distance as the real earth is from the sun the nickel-sized earth would be about 600 feet (183 meters) away from this six-foot (1.83 meter) sun!

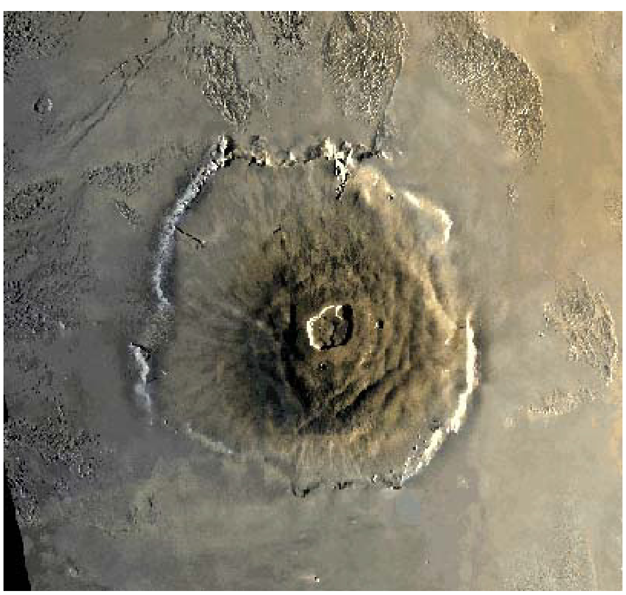
7. Mars

The next dataset is of our nearest planetary neighbor, Mars. We get this dataset from NASA, and it represents the true colors of Mars. Notice that it is rotating on a slanted axis: Mars does in fact rotate on a tilted axis of about 25°, meaning Mars has seasons just like the Earth. The Earth's axis tilts about 23.5°, or one and a half degrees less than Mars. There are a couple of interesting features to see on the surface of Mars.

Notice that the Northern hemisphere of Mars is less pockmarked with craters than the southern half. Scientists have long speculated that the lower-elevation northern hemisphere once held vast oceans, which helped erase signs of meteor impacts. Recent data from NASA's Mars Rovers seems to confirm that there was once a great deal of water on the Martian surface. Apparent sedimentary rocks and water flow channels have been observed.

Who has been to the Grand Canyon? What did you say when you first looked down into it? If you're like me, you looked down into it and said, *wow*… The Grand Canyon is huge, over 200 miles – 322 km - long and more than one mile – 1.6 km - deep. Well, see the long gash on the surface of Mars in its southern hemisphere? That is the *Valles Marineris*, or Mariner Valley. It is over 2,500 miles – 4000 kilometers - long, long enough to almost stretch from New York to Los Angeles. Not only is it more than ten times longer than the Grand Canyon, but it is also more than five miles – eight kilometers - deep – five times deeper!

Well, OK, at least the Earth has Mount Everest, right? At 29,035 feet (8850 meters) high it is a pretty respectable peak. Go Earth! Well, see large mountain up and to the left of the *Valles Marineris*? That is *Olympus Mons*, which is an extinct shield volcano. *Olympus Mons* is a volcano that formed over a "hot spot" on the Martian crust. A hot spot is where a planet's magma rises to the surface and punches through, creating a volcano. We have hot spots on earth, too, such as the one under the Hawaiian Islands. But on earth we have huge tectonic plates that are constantly in motion, so when a volcano arises over a hot spot, it eventually moves off, stops growing, and erodes away over time.



Olympus Mons. Illustration: University of North Dakota Volcano Website

Mars doesn't have the plate tectonic activity the Earth has, so once a volcano starts growing it just keeps on going and going and going… Olympus Mons is the highest mountain we know of in the entire solar system, rising -depending on how one measures it - well over 85,000 feet, almost 26 kilometers, over the surface of Mars. It covers so large an area, though, that if you were to stand on its slope you would see only a gentle rise.

Other things to notice on Mars include Hellas Basin; the large bright round area in the southern hemisphere, at 6 miles – 9.66 kilometers - deep and 1300 miles – 2092 kilometers - across it is the deepest part of the planet. It is the result of an ancient asteroid strike.

As you can see here, Mars does have polar ice caps.

The northern ice cap contains over 300,000 cubic miles (1,250,455 cubic kilometers) of frozen water. That sounds like a lot until you compare it to the earth's Antarctic ice cap, which has over 7 million cubic miles (29,177,273 cubic kilometers) of frozen water in it.

8. Paleological Animation

Let’s come back to the Earth we all know and recognize… Well, maybe not.

This actually is the Earth, although not as it is today, rather as it was 600 million years ago (*Sinian Age*). We are going to animate 600 million years of continental drift in a few minutes. But first a little bit about what you are going to see.

This simulation comes to us from ARC Science Simulations of Loveland, Colorado, and is based on research done by Ron Blakey of the Department of Geology at the University of Northern Arizona.

Is anyone here from Indiana? The yellow outline you see here is where the state of Indiana was 600 million years ago. This animation was originally done for a museum in Indiana, but it turns out this is a good way to track where the US was over the span of this demonstration. Most of the action will occur to the right of this, so you may want to arrange yourselves over here.

As the animation starts, notice that there is nothing green on the surface of the Earth. That’s because 600,000,000 years ago there was, well, nothing green on the surface of the Earth. As things move forward here, green shows up about the time it did historically (during the *Silurian Age*, about 440 million years ago). Notice this area – this is *Laurentia*, which will eventually become North America. This down here is *Gondwana*, which when it joins Laurentia becomes *Pangaea*, a supercontinent (during the *Permian Age*, 250-280 millions years ago). These mountains will eventually become the Appalachian Mountains, which are a very old range indeed.

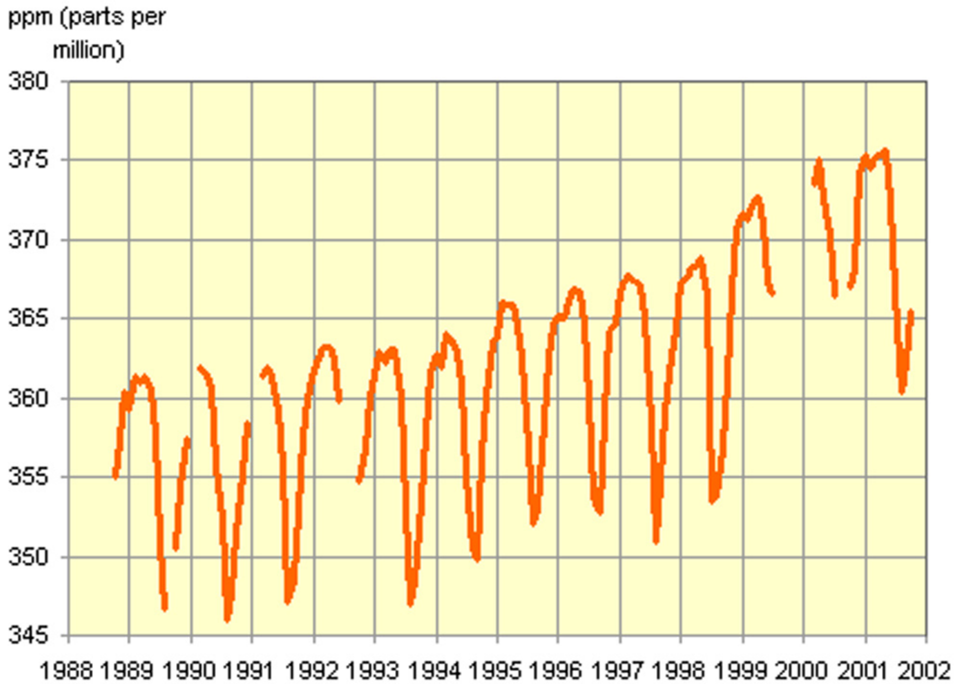
Here we see the Atlantic Ocean starting to form as what will become the mid-Atlantic ridge starts to spread. Notice how relatively late Europe forms up. And then we close in on today.

We’re going to go though this two more times. The next time we’ll stop at three places important in the history of life on Earth.

(Second pass) Once again we see Pangaea forming up during the Permian Age. (The operator) has stopped here at the end of the Permian Age, on the Permian-Triassic boundary about 250 million years ago, when for reasons which are still being debated a sudden ice age caused the extinction of 95% of the life in the oceans and 75% of the life on land. This is the greatest extinction of life on Earth we know of. Seasonal temperatures reached the 100 degrees below zero Fahrenheit – 73.3 degrees below zero Celsius - range even at the equator. Carbon Dioxide levels in the atmosphere dropped to 200 parts per million about this time.

Today’s carbon dioxide levels hover around 365 parts per million:

About this time the dinosaurs start to evolve. And slowly but surely they begin to dominate the surface of the Earth. (The operator) has stopped us here at the height of the Jurassic age, about 160 million years ago, when the planet belonged to the dinosaurs. Something else has happened to make this possible – global warming has become a reality. Carbon dioxide levels have risen to over 2000 ppm. Not only can the dinosaurs dine at the tropics, where the dense jungles are exactly where you would expect them to be, but they can find plenty of food even at the South Pole, where redwood and gingko trees are plentiful. And if they got bored with that they could chow down at the North Pole as well. Both ice caps are long gone by this point.



Source: Kim Holmén, Department of Meteorology, Stockholm University

So the world belongs to the dinosaurs, and as big and fearsome as they were, who was going to challenge that? It was going to be that way forever. Or was it… (The operator) has stopped the animation on what turned out to be a very bad day for the dinosaurs, here at the Cretaceous-Tertiary boundary 65 million years ago. When, from about this direction an asteroid-sized meteorite slammed into what would someday become the Yucatan Peninsula. It pushed up a huge wall of water which immediately – for want of a better term – flushed what would become North America, killing almost everything in its path, and sent up a huge cloud of dust, ash, and other debris into the stratosphere which very quickly covered the earth. This caused a very rapid cool-down of the surface temperatures, dropping the temperatures even at the equator once again to over 100 degrees below zero Fahrenheit, or 73.3 degrees below zero Celsius. (A recently published study of this crater challenges the accepted version, postulating that a different crater is the correct one, but that is arguably an "exception that proves the rule." The event itself is no longer disputed.)

Large, cold-blooded lizards do not do well under these conditions, so after dominating the planet for over a hundred million years, the dinosaurs are wiped out in a matter of less than 5 years – instantaneously, in geologic terms. What do survive such a cataclysm are creatures with feathers who can fly to warmer seasonal climates, and small furry creatures who can hibernate through exceptional cold. So it was a bad day for the dinosaurs, but a good day for mammals and birds, and 65 million years later here we are.

The last time through this animation we're going to see what happens when you combine speed with plate tectonics. Let's move over to this side, where there's only water now but where Asia is going to form up. Asia forms with the collision of a series of islands geologists call the *China Blocks*, and you see them start to move northward now. But look down here at what will become Antarctica – what will become India and Madagascar break off right here. India says good-bye to Madagascar, and watch this – slams into Asia, pushing up the Himalaya Mountains, a process which continues to this day. Mount Everest is in fact about 5 inches or 13 centimeters taller than when Sir Edmond Hillary and Tenzing Norgay climbed it 50 years ago.

9. The Blue Marble

The last display also comes to us from NASA, who calls this the Blue Marble. It is a dataset designed to look like the Earth looks (on the daylight side) on a typical day. The surface detail comes from a number of different satellites, but the vegetation detail comes from the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor-equipped satellite. This means where you see lush green on the surface of the Earth, this is because there's lush green on the surface of the Earth… Where there's dirt brown and sandy yellow, as on the Sahara, well, you get the idea.

The clouds are a composite of three days visible cloud imagery taken in 2001.

The rotation is tilted 23.5 degrees, which happens to be the tilt of the Earth when viewed from space. This is probably as close as most of use will ever get to being an astronaut in outer space looking back at the Earth.

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